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PULMONARY FUNCTIONS IN CONSCIOUS AND ANESTHETIZED RHESUS MONKEY--ETC(U)
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PULMONARY FUNCTIONS IN CONSCIOUS AND ANESTHETIZED RHESUS MONKEYS

ARMY MEDICAL RESEARCH INSTITUTE OF INFECTIOUS DISEASES, FREDERICK, MARYLAND

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Techniques for measurements of selected pulmonary functions in conscious and anesthetized rhesus macaques (Macaca mulatta) are described, and normal base-line values are presented during periods of respiration using pure O_2 or room air. Tidal volume, respiratory rate, minute volume, O_2 consumption, and specific ventilation were determined hourly for a period of 5 hours in conscious monkeys. Additional variables including dynamic pulmonary compliance, pulmonary resistance, specific compliance, intraesophageal pressure, transpulmonary pressure, inspiratory air flow, expiratory air flow, physiological (cont'd)

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dead space, CO_2, output, respiratory quotient and functional residual capacity, as well as arterial blood pH, P_{O_2}, P_{CO_2}, HCO_3^-, and total CO_2 were measured in anesthetized macaques. Further, comparisons of values for certain pulmonary functions were made between this and other studies.

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Pulmonary Functions in Conscious and Anesthetized Rhesus Monkeys

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In conducting the research described in this report, the investigators adhered to the "Guide for the Care and Use of Laboratory Animals," as promulgated by the Committee on the Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Research Council. The facilities are fully accredited by the American Association for Accreditation of Laboratory Animal Care.

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SUMMARY

Techniques for measurements of selected pulmonary functions in conscious and anesthetized rhesus macaques (_Macaca mulatta_) are described, and normal base-line values are presented during periods of respiration using pure O_2 or room air. Tidal volume, respiratory rate, minute volume, O_2 consumption, and specific ventilation were determined hourly for a period of 5 hours in conscious monkeys. Additional variables including dynamic pulmonary compliance, pulmonary resistance, specific compliance, intraesophageal pressure, transpulmonary pressure, inspiratory air flow, expiratory air flow, physiological dead space, CO_2 output, respiratory quotient and functional residual capacity, as well as arterial blood pH, P_{O_2}, P_{CO_2}, HCO_3^- and total CO_2 were measured in anesthetized macaques. Further, comparisons of values for certain pulmonary functions were made between this and other studies.

KEY WORD INDEX--_Macaca mulatta_, pulmonary functions, blood gas tension, base-line values, anesthesia.

INTRODUCTION

Since nonhuman primates are phylogenetically related to man, rhesus and cynomolgus monkeys are commonly used as respiratory models [2,3,8,11,12,15] for studying metabolism,[6,7,23] inhalation toxicity,[13] allergic states,[14,21] asthma,[22] cigarette smoke,[1] and X-irradiation.[5] Although base-line values of pulmonary functions in both conscious and anesthetized monkeys have been reported by several investigators,[2-4,8,11,12,14,15] the data have been incomplete with respect to certain pulmonary functions or the functions were depressed markedly by anesthesia. Further, data variablility as a function of duration of study was not given. The objectives of this study were: (1) to develop techniques for studying selected multiple pulmonary functions in conscious and anesthetized rhesus monkeys, (2) to establish an anesthetized monkey model with minimal depression of pulmonary function, (3) to develop base-line values for major pulmonary functions in anesthetized monkeys and compare them with data obtained by other investigators, (4) to demonstrate the variability of pulmonary data hourly for a period of 5 hours, and (5) to determine if certain respiratory functions are altered by breathing pure O_2 in comparison to room air.

Materials and Methods

Conscious Model Four male rhesus monkeys weighing approximately 3.5 kg were restrained in primate chairs. Before chairing, each monkey was sedated with ketamine HCl (5 mg/kg intramuscularly, im) and the neck hair was closely shaved. After the monkey was completely recovered from effects of ketamine, a head cover (Fig 1) was placed on the top of the chair and the central openings of the soft rubber membranes were fitted properly around the monkey's neck. A thin layer of silicone stopcock grease was applied to the skin of the neck to prevent air leakage from the system. The inlet and outlet processes of the head cover were connected to a 9-liter spirometer[a] (residual volume apparatus) that had been filled with pure O_2 for continuous breathing. After the monkey was adapted to the chair, head cover, and O_2 breathing for 2 hours, tidal volume, respiratory rate, and O_2 consumption were determined hourly for a period of 5 hours. At each hour, a 10-15-minute record was obtained. Minute volume (rate x tidal volume) and specific ventilation (minute volume/O_2 consumption) were calculated, and certain values were also expressed in terms of body surface area.[18]

Anesthetized Model A femoral artery and vein were cannulated under halothane [with O_2 (2%) and maintained at 1.5-1.0%] anesthesia 1 day before measuring pulmonary functions. During an experiment, the monkey was anesthetized again with ketamine (15 mg/kg, im) and a light surgical level of anesthesia was maintained by constant infusion of Na pentobarbital into the femoral vein. The concentration of pentobarbital was (1 mg/cc) and the dose rate was 0.25 mg/minute. The

palpebral reflex was used as an index to determine whether pentobarbital infusion should be continued or discontinued temporarily.

The anesthetized monkey was studied while resting in a supine position. Experiments began 2 hours after completion of endotracheal and intraesophageal intubation. The esophageal tube[b] (i.d. = 6.0 mm, o.d. = 8.5 mm, length = 37.0 cm) was connected to a Statham pressure transducer,[c] and intraesophageal pressure was recorded on a Brush recorder (Fig 2). The intraesophageal pressure was considered as an estimation of intrapleural pressure.[19]

The endotracheal tube was connected sequentially to one of the following devices, while the monkey was breathing room air: (1) pneumotachograph (size 000), (2) 1-way valve or (3) 2-way valve. Tidal volume obtained by electrically integrating the signal from the pneumotachograph and differential pressure transducer,[e] registering on a Brush recorder. The information on tidal volume and intraesophageal pressure was sent to a digital signal analyzer[f] and stored on magnetic tape.[g] Transpneumotachographic pressure was calculated from the air flow rate during inspiration with known pressure calibration. The difference between measured intraesophageal pressure and calculated transpneumotachographic pressure was defined as transpulmonary pressure.

The 1-way valve was used to separate inspired and expired air, which flowed continuously (50 ml/minute) into a CO_2 analyzer[h] for CO_2 concentration (volume %) determination. The 2-way valve was connected to a 9-liter spirometer containing 100% O_2 for tidal volume, respiratory rate, and O_2-consumption determination. Using the same 2-way valve and spirometer, functional residual capacity (FRC) was measured by the helium dilution technique.

Dynamic pulmonary compliance and resistance were calculated by the method described by Giles et al[10] except that the present data were calculated manually. Magnetically recorded tidal volume and intraesophageal pressure were redisplayed on a digital signal averager and the magnitude and time for determinations of isovolumetric points were accurately measured. Equations in Table 1 were used to calculate various pulmonary functions, and certain variables were also expressed in terms of m^2 of body surface area.[18]

Two 1-ml blood samples were taken from the femoral artery, when the monkey was breathing pure O_2 or room air. Arterial blood pH, P_{O_2}, total CO_2, HCO_3^- and base excess were determined in a blood gas analyzer.[1] Blood gases and pH values, as well as certain pulmonary variables were compared between breathing O_2 and room air.

Statistics. An independent t test was used to compare corresponding pulmonary function measurements in conscious and anesthetized monkeys. When comparisons were made hourly in the same monkey during the 5-hour experiment, a paired t test was used. Data obtained by other investigators[5,8,11,12,14,15,23] were presented as mean, standard deviation, range, or 95% confidence limit (1.96 x standard error of the mean). Comparisons between the present and others' data on pulmonary functions in the anesthetized rhesus monkeys were based upon whether the present data mean values fell within or outside the range of 95% confidence limits of the data of other investigators.

Results

Normal values for various pulmonary functions, including lung volumes, ventilation, and breathing mechanics of anesthetized rhesus monkeys breathing

room air, are summarized in Table 2. During a 5-hour period, all measured values varied slightly, except for respiratory rate, which was significantly depressed between 3 and 4 hours. Physiological dead space fluctuated and dynamic pulmonary resistance increased gradually as a function of time; however, these changes were not significant.

Selected pulmonary functions were compared between conscious and anesthetized monkeys during a period of 5 hours (Table 3). Among all measured parameters, there were no significant differences between the 2 groups of monkeys studied.

Values for respiratory quotient (RQ) are presented in Table 4. Similarities of expired CO_2 concentration, CO_2 output, arterial blood pH, P_{CO_2}, total CO_2 and base excess between breathing pure O_2 and room air are tabulated in Tables 4 and 5. Blood P_{O_2}, was much higher in monkeys breathing pure O_2 than room air (Table 5). Values of RQ, blood pH, and gas tensions were maintained in a relatively constant state throughout a 5-hour period.

Data on various pulmonary functions, O_2 consumption, and RQ in anesthetized rhesus monkeys from this and other studies are summarized in Tables 6 and 7. In general, results from the present study agree well with the findings of others, except that higher values for O_2 consumption (compared to Rakieten[23]) were demonstrated. The present work also showed higher values for tidal volume, respiratory rate, and minute volume as compared to reported data of Kelly et al.[14] Further, the measured tidal volumes of this study were higher than values obtained by Crosfill and Widdicombe[8] and Guyton.[11]

Discussion

Although pulmonary depression is commonly seen in man and animals under anesthesia, respiratory functions of anesthetized monkeys in this study were not modified significantly compared to data obtained from conscious monkeys. However, the anesthetized monkey showed a trend toward an increased dynamic pulmonary resistance as a function of time. Since few respiratory measurements can be carried out in a conscious monkey, the lightly anesthetized monkey seems to be acceptable for establishing normal values for pulmonary functions, O_2 consumption, CO_2 output and RQ.

Major advantages for using the lightly anesthetized monkey include: (1) a great variety of pulmonary functions can be measured; (2) results are not influenced by the monkey's emotions and its associated muscular activities; (3) monkeys recover completely after these measurements of pulmonary function; and (4) monkeys may be used for short-term experiments for evaluation of drugs or toxin. When conscious chaired monkeys are used, the head cover provides minimum disturbances or stimulation to the monkey as compared to the use of a face mask. Further, the closed head cover is suitable for continuous application of O_2, aerosol, or positive-pressure breathing for the treatment of pulmonary edema.[17]

Normal values for arterial blood gases and pH in conscious rhesus monkeys have been reported by Liu,[16] Munson et al,[20] Forsyth and coworkers,[9] and Binns et al.[3] In the present study, arterial blood values for anesthetized monkeys showed slight decreases in pH, P_{O_2} as compared to several other investigators.[9,20] However, the present data on arterial blood pH, P_{O_2} and P_{CO_2} agree well with Binns et al[3] and our previous findings in conscious rhesus monkeys.[16] This evidence supports the

observations that monkeys used in this study were not deeply anesthetized.

There were few differences in arterial blood pH, P_{CO_2}, HCO_3^-, total CO_2, and base excess between breathing pure O_2 or room air in anesthetized monkeys. However, blood P_aO_2 increased from 83-94 mm Hg to 367-411 mm Hg during pure O_2 breathing. These appeared to be the highest values for P_{O_2} in the arterial blood of lightly anesthetized monkeys.

Some unique aspects of the present study may be summarized as follows: (1) no significant differences of measured respiratory values were found between conscious and anesthetized models; (2) many respiratory and metabolic variables can be measured in a single lightly anesthetized monkey; (3) the measured respiratory values, except dynamic pulmonary resistance and physiological dead space, remained relatively constant throughout a period of 5 hours; and (4) transpulmonary pressure was calculated by the difference of intraesophageal and transpneumotachographic pressures during inspiration.

In general, values for respiratory and metabolic functions agree well with other workers.[5,8,11,12,14,15,23] However, values for O_2 consumption and tidal volume were higher in this study than those obtained by other investigators.[8,11,14,23] These discrepancies may result from different levels of anesthesia applied to rhesus monkeys.

Footnotes

[a]Warren E. Collins, Inc., Braintree, Ma. (All original hoses were replaced by small Tygon tubing (i.d. = 10 mm, o.d. = 14.6 mm).

[b]"Argyle" Sherwood Medical Industries, St. Louis, Mo.

[c]Statham, P23BB, Hato Rey, Puerto Rico.

[d]Dynasciences Medical Products, Blue Bell, Pa. 19422.

[e]Statham, PM15E, Hato Rey, Puerto Rico.

[f]Northern NS-575, Northern Scientific, Inc., Middleton, Wi.

[g]Northern NS-408F, Northern Scientific, Inc., Middleton, Wi.

[h]Model 2050, Harvard Apparatus Co., Millis, Ma.

[i]Corning model 165, Corning Scientific Instruments, Medfield, Ma.

TABLE 1--Equations for Calculating Pulmonary Functions

Variable	Equation
Physiological dead space (V_D)*	V_D (ml) = $(P_aCO_2 - P_ECO_2) \cdot V_T/P_aCO_2$
Functional residual capacity (FRC)**	FRC (ml) = $V_1\ [(N_1 - N_2)/N_2]$
CO_2 output	CO_2 output (ml/min) = minute vol (ml/min) · CO_2 conc. (vol %) in the expired air.
Dynamic pulmonary compliance (DPC)	DPC (ml/cm H_2O) = $\frac{\text{Tidal volume (ml)}}{\text{Transpulmonary pressure (cm } H_2O)}$
Dynamic pulmonary resistance (DPR)	DPR (cm H_2O/L/sec) = $(P_1 - P_2)/(F_1 + F_2)$.
Respiratory quotient (RQ)	RQ = CO_2 output (ml/min)/O_2 consumption (ml/min)

*P_aCO_2 = PCO_2 in arterial blood (mm Hg), P_ECO_2 = PCO_2 in expired air (mm Hg), V_T = Tidal vol (ml).

**N_1 (vol %) = Helium (He) concentration before connecting to the monkey, V_1 = vol of He (250 ml) and air in the spirometer = (250 ml/N_1), N_2 = He concentration after connecting to the animal at the end of expiration.

P_1 and P_2 are intraesophageal pressure levels at isovolumetric points of tidal volume, F_1 and F_2 are inspiratory and expiratory flow levels at isovolumetric points of tidal volume.

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TABLE 2--Pulmonary Functions in Anesthetized Normal Rhesus Monkeys Breathing Room Air

Classification	Variable	Value at time in hours				
		1	2	3	4	5
Lung volume	Tidal volume (ml)	35 ± 4	37 ± 4	36 ± 4	41 ± 7	41 ± 6
	Tidal volume (ml/m^2L)	129 ± 11	139 ± 15	135 ± 16	152 ± 20	153 ± 21
	FRC (ml)	119 ± 12	108 ± 8	111 ± 7	113 ± 10	112 ± 9
	FRC (ml/m^2)	454 ± 44	408 ± 26	419 ± 24	423 ± 30	426 ± 36
Pulmonary ventilation	Respiratory rate (cycle/min)	39 ± 2	35 ± 1	28 ± 2*	28 ± 2*	35 ± 2
	Minute volume (liter/min)	1.36 ± 0.16	1.30 ± 0.16	0.98 ± 0.13	1.21 ± 0.23	1.44 ± 0.26
	Minute volume ($ml/min/m^2$)	4.99 ± 0.4	4.84 ± 0.5	3.74 ± 0.5	4.43 ± 0.8	5.26 ± 0.7
	Physiological dead space (ml)	4.33 ± 1.97	0.64 ± 3.65	2.52 ± 2.44	0.97 ± 3.9	0.45 ± 3.9
Mechanics of breathing	Intraesophageal pressure (cm H_2O)	-5.7 ± 0.6	-6.6 ± 0.7	-5.6 ± 0.8	-6.5 ± 0.8	-7.1 ± 0.9
	Transpneumotach pressure (cm H_2O)	1.13 ± 0.09	1.05 ± 0.10	0.85 ± 0.07	0.99 ± 0.12	1.05 ± 0.12
	Transpulmonary pressure (cm H_2O)	-4.54 ± 0.55	-5.58 ± 0.67	-4.75 ± 0.78	-5.50 ± 0.76	-6.03 ± 0.91
	Expiratory flow (ml/cm H_2O)	66.6 ± 6.1	65.0 ± 9.0	56.9 ± 8.7	58.6 ± 7.8	61.9 ± 7.5

TABLE 2--Continued

Inspiratory flow (ml/sec)	64.0 ± 5.1	59.5 ± 5.9	48.4 ± 3.7	56.1 ± 6.6	59.5 ± 6.8
Dynamic pulmonary compliance (ml/cm H_2O)	8.2 ± 0.9	7.3 ± 1.1	9.4 ± 1.8	8.6 ± 1.7	7.9 ± 1.7
Dynamic pulmonary resistance (cm H_2O/liter/sec)	19.1 ± 5.2	31.3 ± 7.9	32.7 ± 7.8	33.2 ± 5.7	40.9 ± 10
Specific compliance [(compliance/FRC)10^{-3}]	72 ± 9	66 ± 9	83 ± 14	75 ± 13	52 ± 7

All values are means ± 1 standard error of the mean (n=9).

*$P < 0.05$.

TABLE 3--Comparisons of Selected Pulmonary Functions between Conscious and Anesthetized* Rhesus Monkeys while Breathing O_2

Variable	Group (n)	Value by time in hours				
		1	3	4	5	6
Tidal volume (ml)	Conscious	40 ± 6	41 ± 5	40 ± 6	40 ± 6	40 ± 6
	Anesthetized	33 ± 3	38 ± 4	41 ± 4	42 ± 3	42 ± 3
Tidal volume (ml/m^2)	Conscious	164 ± 30	169 ± 27	164 ± 30	164 ± 30	164 ± 30
	Anesthetized	124 ± 10	142 ± 11	155 ± 14	157 ± 12	157 ± 11
Respiratory rate (cycle/min)	Conscious	28 ± 3	27 ± 3	27 ± 3	25 ± 2	24 ± 3
	Anesthetized	27 ± 1	24 ± 1	21 ± 2	22 ± 1	21 ± 2
Minute volume (liter/min)	Conscious	1.10 ± 0.15	1.08 ± 0.14	1.30 ± 0.14	0.99 ± 0.14	0.94 ± 0.12
	Anesthetized	0.90 ± 0.08	0.89 ± 0.05	0.81 ± 0.03	0.86 ± 0.05	0.85 ± 0.05
Minute volume ($liter/min/m^2$)	Conscious	4.62 ± 0.73	4.54 ± 0.61	4.34 ± 0.62	4.16 ± 0.64	3.97 ± 0.53
	Anesthetized	3.34 ± 0.25	3.37 ± 0.18	3.11 ± 0.20	3.43 ± 0.15	3.24 ± 0.25
O_2 consumption (liter/hr)	Conscious	3.56 ± 0.32	3.49 ± 0.49	3.33 ± 0.41	2.84 ± 0.27	3.02 ± 0.53
	Anesthetized	3.55 ± 0.48	3.95 ± 0.45	3.12 ± 0.38	3.65 ± 0.30	3.14 ± 0.24
O_2 consumption ($liter/hr/m^2$)	Conscious	14.7 ± 1.0	14.5 ± 1.7	13.8 ± 1.3	11.8 ± 0.8	12.4 ± 1.7
	Anesthetized	13.5 ± 1.8	15.0 ± 1.6	12.1 ± 1.5	13.8 ± 0.7	12.1 ± 1.7
Specific ventilation (minute vol/ O_2 consumption)	Conscious	17.8 ± 1.7	18.0 ± 1.1	20.1 ± 2.2	18.1 ± 2.0	19.0 ± 2.8
	Anesthetized	16.3 ± 1.9	14.2 ± 1.1	16.3 ± 1.2	15.1 ± 0.8	16.6 ± 1.4

All values are means ± 1 standard error of the mean: n=4 for conscious, n=9 for anesthetized.

*Anesthesia: 15 mg/kg ketamine (IM) + 0.25 mg/min of Na pentobarbital (intermittent IV infusion).

TABLE 4--RQ Values and Comparisons of Expired CO_2 Concentration and CO_2 Output between Breathing Pure O_2 and Room Air in Anesthetized Rhesus Monkeys

Variable	Gas breathed	Value by time in hours 1	2	3	4	5
RQ	Pure O_2	0.80 ± 0.08	0.70 ± 0.07	0.82 ± 0.05	0.75 ± 0.05	0.82 ± 0.08
Expired CO_2	Pure O_2	5.03 ± 0.29	4.93 ± 0.27	5.12 ± 0.23	5.00 ± 0.22	4.97 ± 0.25
(vol %)	Room air	4.22 ± 0.13	4.26 ± 0.16	4.38 ± 0.18	4.44 ± 0.13	4.21 ± 0.19
CO_2 output	Pure O_2	2.45 ± 0.19	2.66 ± 0.22	2.50 ± 0.18	2.72 ± 0.18	2.54 ± 0.23
(liter/hr)	Room air	3.49 ± 0.40	3.39 ± 0.43	2.62 ± 0.36	3.27 ± 0.65	3.64 ± 0.71
CO_2 output	Pure O_2	10.0 ± 0.8	10.0 ± 0.7	9.6 ± 0.8	10.3 ± 0.6	9.7 ± 0.9
(liter/hr/m^2)	Room air	13.0 ± 1.2	12.6 ± 1.4	10.0 ± 1.4	12.1 ± 2.2	13.7 ± 2.1

All values are means ± 1 standard error of the mean.

TABLE 5--Comparisons of Arterial Blood pH, Gas Tension HCO_3^-, Total CO_2, and Base Excess between Breathing Pure O_2 and Room Air in Anesthetized Rhesus Monkeys

Variable	Gas breathed	Value by time in hours				
		1	2	3	4	5
pH	O_2	7.374 ± 0.009	7.364 ± 0.009	7.362 ± 0.008	7.369 ± 0.009	7.365 ± 0.010
	Room air	7.377 ± 0.005	7.378 ± 0.007	7.374 ± 0.010	7.372 ± 0.011	7.376 ± 0.011
PO_2	O_2	367 ± 32	370 ± 27	389 ± 23	407 ± 12	411 ± 16
(mm Hg)	Room air	83.2 ± 4.2	88.7 ± 7.5	88.8 ± 3.6	93.7 ± 5.4	88.9 ± 3.6
PCO_2	O_2	33.4 ± 2.4	31.6 ± 3.0	33.0 ± 2.8	31.5 ± 2.2	31.3 ± 2.6
(mm Hg)	Room air	30.2 ± 2.5	28.2 ± 3.1	30.2 ± 2.9	28.5 ± 2.6	28.0 ± 2.9
HCO_3^-	O_2	19.1 ± 1.5	18.2 ± 1.9	19.0 ± 1.7	17.8 ± 1.6	18.1 ± 1.7
(mM/liter)	Room air	18.5 ± 1.5	16.7 ± 1.8	18.1 ± 1.7	17.1 ± 1.8	16.8 ± 1.8
Total CO_2	O_2	20.4 ± 1.5	19.7 ± 1.9	20.6 ± 1.7	19.5 ± 1.5	19.6 ± 1.6
(mM/liter)	Room air	20.2 ± 1.6	18.1 ± 1.8	19.5 ± 1.8	18.4 ± 1.8	18.3 ± 1.8
Base excess	O_2	-3.7 ± 1.3	-5.1 ± 1.7	-4.2 ± 1.4	-5.0 ± 1.4	-5.0 ± 1.4
(mM/liter)	Room air	-4.2 ± 1.3	-5.7 ± 1.6	-4.8 ± 1.5	-5.6 ± 1.6	-5.7 ± 1.6

All values are means ± 1 standard error of the mean (n=9).

TABLE 6--Comparison of Values Obtained by Authors and Other Investigators for Respiratory Rate, Tidal Volume, and Minute Volume in Anesthetized Rhesus Monkeys.

No. of animals (wt in kg)	Rate (cycle/min)	Tidal volume (ml)	Minute volume (ml/min)	Reference
9*	33.1 ± 5.4	38 ± 15.1	1256 ± 561	Present study
(3.5 - 6.6)	(21 - 48)	(12.7 - 79)	(570 - 2848)	
11	39	42	1650	Brooks et al (5)
(3.1 - 5.4)				
4	33	20	700	Crosfill et al (8)
(1.8 - 3.1)	(27 - 47)	(9 - 29)	(269 - 1340)	
14	42 ± 7	43.5 ± 8.1	1791 ± 360	Lees et al (15)
(Avg 5.3)	(28.3 - 55.7)**	(27.6 - 59.4)**	(1067 - 2514)**	
6	40	21.2	863	Guyton (11)
(Avg 2.7)	(31 - 52)	(8.8 - 29.1)	(311 - 1410)	
6			1443	Hayden (12)
(Avg 7.6)	--	--	(1069 - 1855)	
21	26.4 ± 7.9	27.7 ± 6.9	709 ± 207	Kelly et al (14)
(2.5 - 6.1)	(24.1 - 28.6)**	(26.7 - 28.7)**	(651 - 767)**	

All values are means ± 1 standard deviation with ranges in parentheses except **.

* No. of observations = 45.

** 95% confidence limit of mean (1.96 x standard error of the mean).

TABLE 7--Comparison of values obtained by authors and other investigators for selected pulmonary RQ and O_2 consumption in rhesus monkeys

Condition of monkeys	No. of monkeys (wt. in kg)	FRC (ml)	Dead space (ml)	Dynamic pulmonary compliance (ml/cm H_2O)	Expiratory flow (ml/sec)
Anesthetized	9*	112.7 ± 82	5.68 ± 36	8.3 ± 4.3	61.8 ± 12.3
	(3.5 - 6.6)	(73.6 - 205)	(-16.2 - 11.2)	(2.7 - 19.9)	(23.4 - 115.9)
	11				
	(3.1 - 5.4)	--	--	--	
	4	87.5	--	12.3	--
	(1.8 - 3.1)	(61 - 115)		(7.1 - 20.2)	
	14	--	12.6 ± 26.5	--	--
	(Avg 5.8)		(-1.3 - 26.5)**		
	11	--	--	--	--
	(2.7 - 3.6)				
	8	--	--	--	69.1 ± 20.9
	(Avg 7.6)				(53.6 - 84.6)**
	21	--	--	15.2 ± 10.0	
	(2.5 - 6.1)			(7.8 - 22.6)**	
Conscious	8	--	--	10.3 ± 2.9	--
	(2.4 - 4.3)			(5.2 - 14)	

All values are means ± 1 standard deviation in parentheses except **.
*No. of observation = 45, except dead space, which is 30.
**95% confidence limit of mean (1.96 x standard error of the mean).

TABLE 7--Concluded

Dynamic pulmonary resistance (cm H_2O/L/sec)	RQ	O_2 consumption (ml/min)	Transpulmonary pressure (cm H_2O)	Reference
31.4 ± 23.4	0.78 ± 0.54	59.0 ± 37.2	5.3 ± 2.2	Present study
(2.8 - 108.4)	(0.45 - 1.38)	(24.9 - 93)	(2.1 - 11.9)	
--	--	--	--	Brooks et al (5)
--	--	--	--	Crosfill et al (8)
--	0.77 ± 0.11	55.2 ± 49.3	--	Lees et al (15)
	(0.72 - 0.82)**	(28.6 - 81.8)**		
--	0.75 ± 0.02	22.7 ± 2.61	--	Rakieten (24)
	(0.73 - 0.75)**	(21.1 - 24.3)**		
--	--	32.2	--	Hayden (12)
24.8 ± 13.7	--	--	--	Kelly et al (14)
(14.6 - 34.9)**				
22.0 ± 11.0	--	--	3.9 ± 0.6	Binns et al (3)
(10 - 44)			(2.9 - 4.8)	

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Figure Legends

Fig 1--Three major parts of a head cover for a chaired conscious monkey.

Fig 2--Equipment arrangement for studying pulmonary function in an anesthetized monkey.

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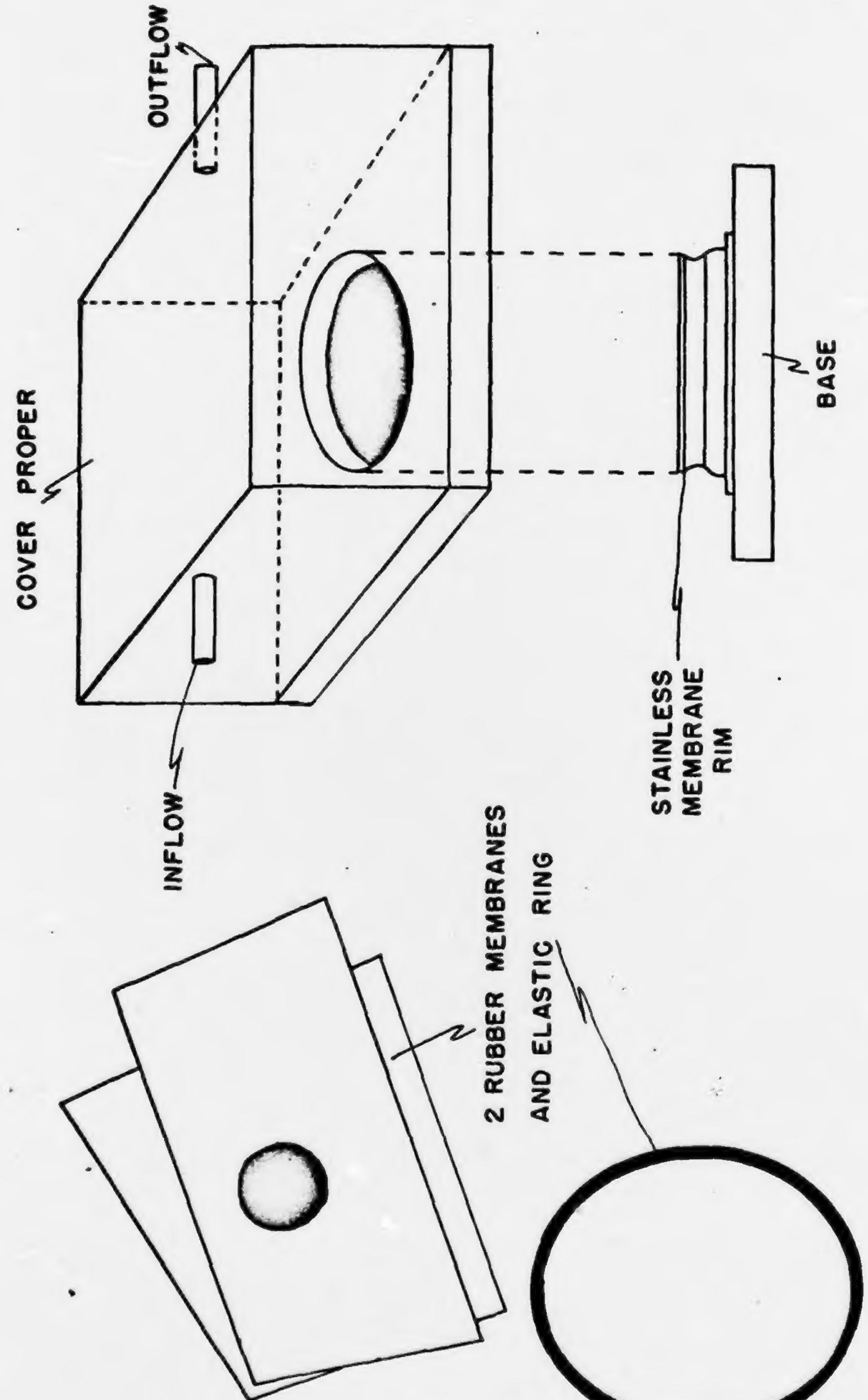
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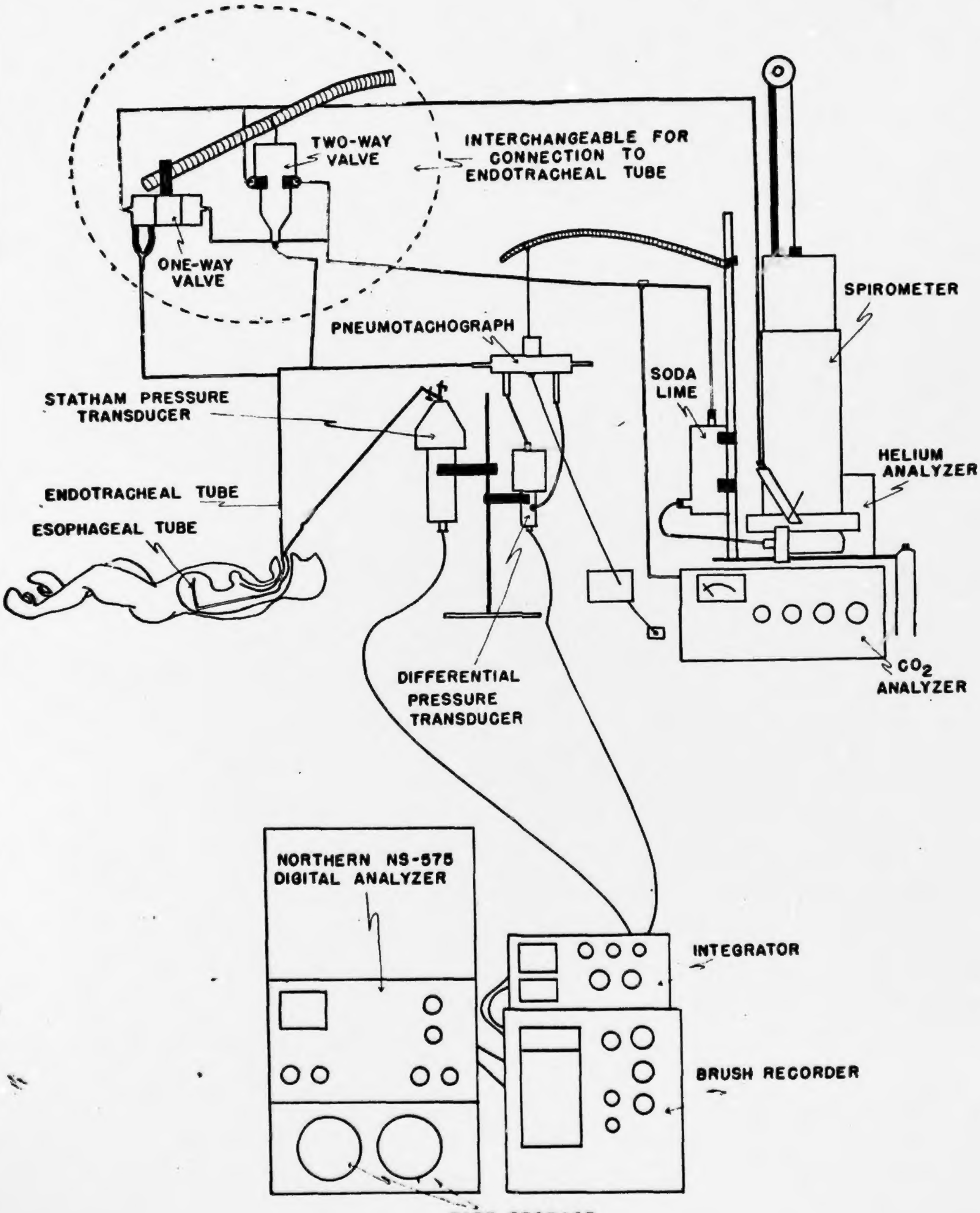
TWO-WAY VALVE
INTERCHANGEABLE FOR CONNECTION TO ENDOTRACHEAL TUBE
ONE-WAY VALVE
SPIROMETER
PNEUMOTACHOGRAPH
SODA LIME
STATHAM PRESSURE TRANSDUCER
HELIUM ANALYZER
ENDOTRACHEAL TUBE
ESOPHAGEAL TUBE
CO_2 ANALYZER
DIFFERENTIAL PRESSURE TRANSDUCER
NORTHERN NS-575 DIGITAL ANALYZER
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